RESEARCH DEPARTMENT

The production of sinusoidal resolution bar patterns for inclusion in the television test cards 'D' and 'E'

TECHNOLOGICAL REPORT No. T-137

1964/69

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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ADDENDUM

RESEARCH DEPARTMENT - BRITISH BROADCASTING CORPORATION

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Whilst sinusoidal test patterns have a particular advantage for objective measurements, it has since been found that in a broadcast test card their subjective appearance can be misleading. The design of test cards 'D' and 'E' is therefore under review.

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October 1964

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SUMMARY

The methods previously used for the production of sinusoidal bar patterns are first discussed and their limitations given. A modified form of one of these systems using rotating polaroid filters and a travelling slit is fully described together with the methods used in determining the various parameters and details of processing of the exposed image. The results are shown to be within the tolerances given by the specification.

1. INTRODUCTION

In any optical image-forming system it is usual to describe the performance in terms of resolution in patterns per unit dimension and in image acutance. It is an accepted practice in image assessment to use resolution bars having a rectangular profile, but varying in mark-to-space ratio and density range. One of the attendant problems associated with the electrical signals generated by the scanning of resolution bars having a rectangular profile is that unless unlimited bandwidth is used, some form of harmonic distortion is unavoidable. It is therefore desirable to use a form of resolution pattern that has a sinusoidal profile, thus overcoming this distortion. If a system is tested using sinusoidal bar patterns, the limiting resolution is revealed by a progressive decrease of modulation as bar patterns of increasing frequency are used. The use of sinusoidal bar patterns is therefore highly desirable, but unfortunately their photographic production presented a number of problems and these are discussed in this report.

2. INITIAL REQUIREMENTS

A series of bar patterns having sinusoidal distribution was required for inclusion in Test Cards 'D' and 'E'. They were to be produced in blocks of different frequencies and they were to conform to a specified density range. A specification for these bars is shown in Table 1.

TABLE 1

Sinusoidal Resolution Bar Patterns

REFLEXION DENSITY RANGE	FREQUENCIES Mc/s
White 0·5	1·0, 1·5, 2, 2·5, 2·75, 3·0 Test Card 'D'
Black 1·05	1·5, 2·5, 3·5, 4·0, 4·5, 5·25 Test Card 'E'

The final bars were to be printed on single-weight glossy bromide paper. The densities quoted are single-diffuse. The size of the final block of bars was to conform to drawing No. 1000.2.14K issued by Planning and Installation Department.

3. EXPERIMENTAL PRODUCTION TECHNIQUES

3.1. Previously used Methods of Production

Various techniques have been used previously to produce, by photomechanical means, sine-wave bars on a photographic emulsion. One method referred to by Kapany and Pike[1] shows how a static and a rotating polaroid screen can together be used to produce sinusoidal modulation of a beam of light. If a rotating slit is placed in front of these screens and then photographed, sinusoidal bar patterns would be obtained. These patterns would however be in the form of radials and therefore unsuitable for the proposed test cards. An electronic method utilizing a television display has been used by Hersee[2] to produce the sine-wave bar patterns for BBC Test Card 51. It would, nevertheless, have been extremely difficult to have adopted this system and to have met the present specification.

There are other purely optical methods, but in general their instrumentation is rather elaborate and they tend to be somewhat inflexible; therefore, in order to produce a range of bar patterns and maintain close control over the density range, it was decided to use the method of rotating polaroid screens referred to by Kapany and Pike, but with a modified system of scanning.

3.2. Equipment

As the task in hand required the use of what was basically photographic equipment, it was decided to undertake some experiments for converting a Model 3.S Durst Laborator enlarger to take rotating polaroid screens, and to mount a traversing slit in the plane of the photographic negative. The layout is shown in Fig. 1.

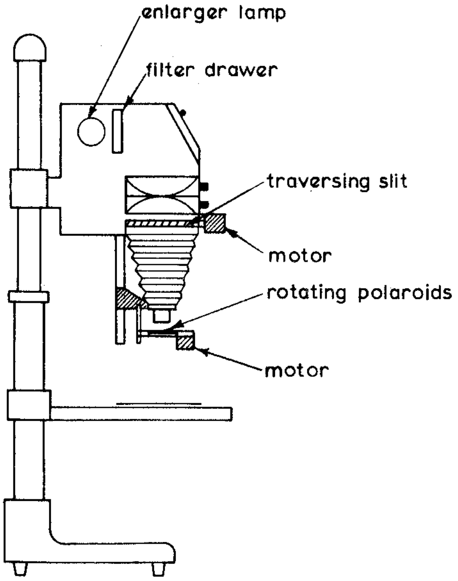

Fig. 1 - Initial layout of enlarger

3.3. Rotating Polaroid Screens

Measurements of the polaroid screens revealed that a high overall density range could be obtained, and initially it was decided to situate the rotating mechanism under the lens. One screen was fixed and the other rotated by a lightweight synchronous motor having torque of approximately 4 gm-cm. The rotating drive was effected through a 200 : 1 gear reduction train to the rim of the polaroid screen; power for the motor was obtained from an amplifier which in its turn was driven by a generator capable of giving an output having a variable frequency. By this means the speed of rotation of the polaroid filter could be varied with precision between 1 and 6 rev/min by altering the frequency of the generator output from 50 to 300 c/s.

3.4. Slit Mechanism

The scanning device was mechanical and took the form of a slit of variable width mounted on a carriage that required to be moved across the negative plane of the enlarger at a constant velocity. The original drive for this carriage was a lead screw and nut made especially for the purpose, the layout of which is shown in Fig. 2. To enable the slit velocity to be evaluated when using this drive, a slit width of only 0·01 mm was first employed. The enlarger lamp was fed from a stabilized source and the image of the slit projected on to bromide paper fixed to the enlarger baseboard. The slit was then allowed to traverse the length of the lead screw whilst the enlarger continuously exposed the image of the slit on the bromide paper. It was found on development of the print that the recorded image revealed not a perfect overall grey, but a series of bars of different densities and widths. These were, in fact, a record of minor inaccuracies in the lead screw and nut. To overcome this difficulty the lead screw and nut were replaced by a standard micrometer screw of 0·5 mm pitch and the slit mechanism was lightly loaded against the head of the screw to minimize back-lash as shown in Fig. 3. The results obtained from this modified drive were a great improvement over those obtained from the original system. The screw was driven through a gear train by a similar motor to that used for the polaroid screen so that both movements could be synchronized or bear a constant preset relationship to one another, In practice, it was found beneficial to run the slit drive motor at a constant speed of 200 rev/min using stabilized electricity supply voltage at a frequency of 50 c/s and restrict the use of the variable-frequency output from the generator to the polaroid drive motor alone. This gave a slit speed of 1·875 mm per minute.

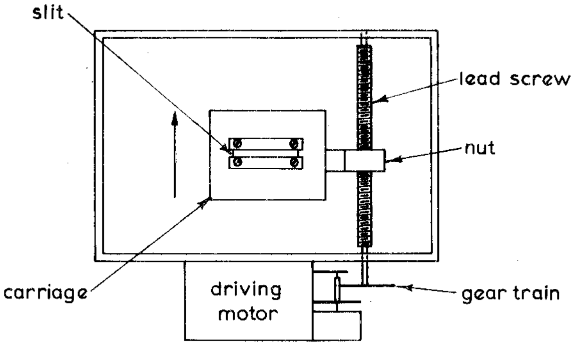

Fig. 2·- Lead screw and nut

3.5. Experimental Results

Having obtained a constant velocity for the slit, a series of tests was commenced to evaluate the photographic record of the resultant bars. As the initial tests were to explore the basic idea, the principal objective was to ascertain that a series of recorded bar patterns had a sinusoidal distribution throughout. Unfortunately, although the waveform was approximately correct, the resultant bars appeared to be pairing over the whole of the area exposed.

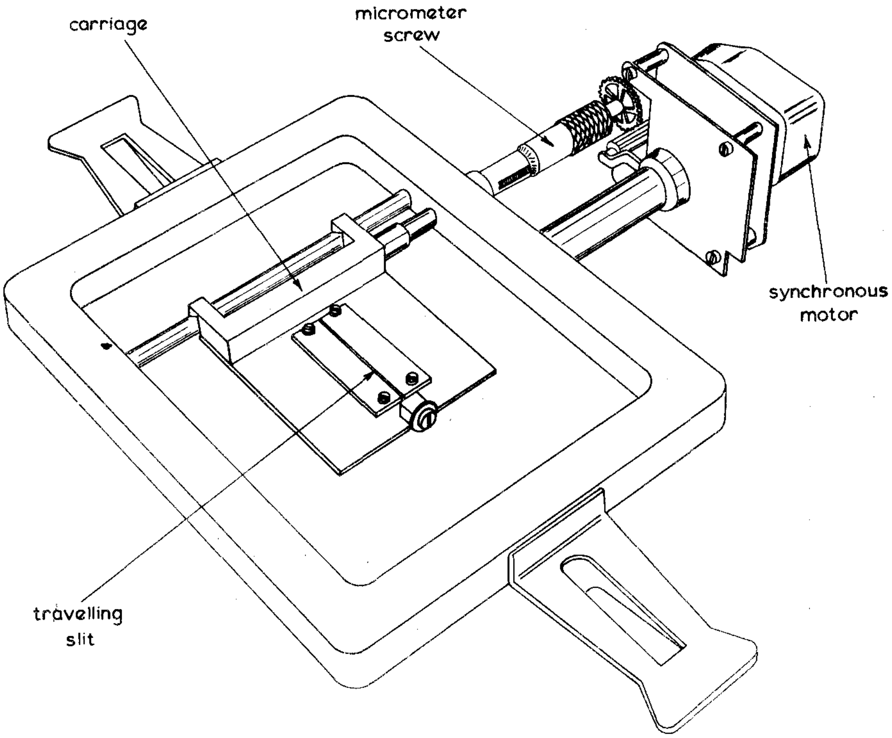

Fig. 3 - Slit carriage with micrometer lead screw

A further problem was that small particles of dust became lodged between the blades of the very narrow slit used. This caused a series of lines to be drawn across the image recorded on the photographic plate.

3.6. Bar Pairing

The effect of bar pairing proved to be an elusive problem to solve. Upon measurement it was discovered that two consecutive cycles of polarization were unequal in their effect. Attempts were made to correct this by placing the stationary polaroid at various positions in the enlarger's optical system. A third polaroid was introduced to lie over the traversing slit, but although it diminished the effect, the pairing was still apparent. A solution was eventually found by dispensing with the rotating polaroids under the lens and situating them next to the enlarging lamp. The pairing effect had been caused by a partial polarization of the light in the enlarger optics and it was therefore necessary to polarize the light at its source. As this particular enlarger had a colour filter drawer immediately in front of the lamp, it was convenient to redesign the rotating polaroids so that a compact assembly could be mounted in place of the filter drawer. This assembly is shown in Fig. 4. The final mechanical arrangements employed are shown in Figs. 5 and 6. They gave a flexible system of production having the following features:-

(a) Variable speed of polaroid rotation. This controlled the number of bar patterns recorded.

(b) Uniform speed of slit traverse.

(c) Variable slit width controlling depth of modulation.

(d) Variable magnification, also controlling (b) and (c).

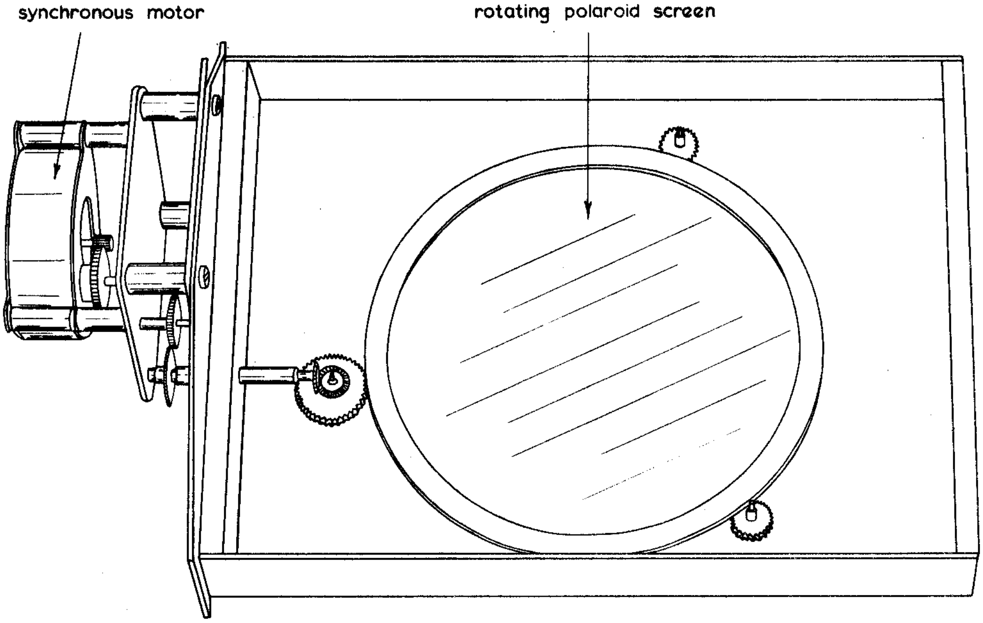

Fig. 4 - Rotating polaroid assembly

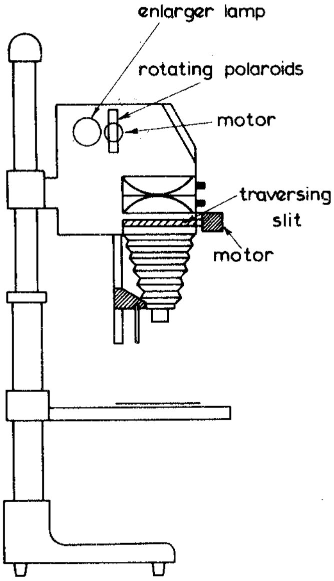

Fig. 5 - Final layout of enlarger

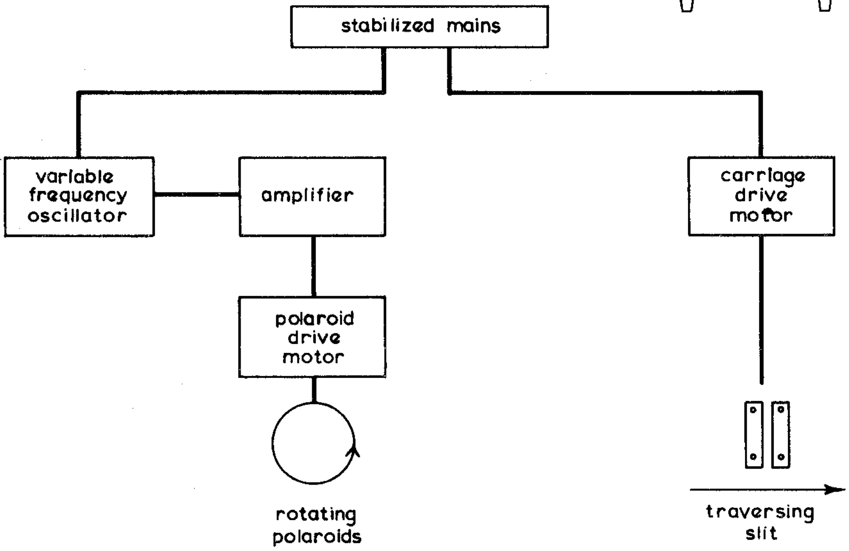

Fig. 6 - Equipment layout - block schematic

4. THEORETICAL CONSIDERATIONS

If light of intensity I is sinusoidally modulated into the form I_m*, Fig. 7(a), by means of the polaroid filter and travelling slit, and in this form is projected on to a photographic emulsion, then on development this emulsion will have a transmission characteristic in the form of $1/I_m$, Fig. 7(b). If this recorded image is exposed to a uniform light source and a print obtained, then this print will have a transmission characteristic, Fig. 7(c), similar to that given by the original light and slit combination, providing the following conditions are fulfilled:-

(a) That the emulsion used has a density/log exposure characteristic that is linear over the range required.

(b) That the overall processing is controlled to a gamma of one.

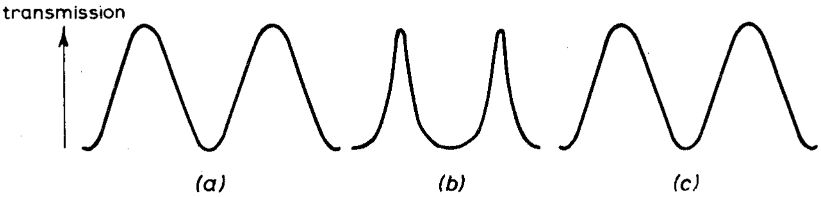

Fig. 7 - A plot of sine-wave profiles

(a) I_m from polaroid assembly
(b) $1/I_m$ from intermediate negative
(c) I_m from final print

5. THE PRODUCTION OF THE MASTER INTERMEDIATE NEGATIVE

5.1. Exposure

It was determined empirically that the final master negative from which all the bars could be produced would be one containing 24 sinusoidal cycles and be 75 mm long overall. This number of cycles was in excess of those necessary to cover both the maximum frequencies required on Test Cards 'D' and 'E', but it was anticipated that they would be needed for other specialized test patterns. The overall length of 75 mm was chosen because it was a convenient size to handle in the enlarger and a wide range of photographic materials was available in this size from which the master negative could be reproduced. By setting the enlarger at a 5 : 1 ratio between the negative holder containing the slit and the copy board, the slit travel to produce this master negative 75 mm long would therefore be reduced by the enlarger ratio, i.e. 75/5 mm to a dimension of 15 mm; this was well within the limits of the micrometer screw actuating mechanism of the slit. From the mode of operation of the equipment it may be seen that the wavelength, λ, of the bar patterns is inversely proportional to the frequency of modulation, f_m, given by the rotating polaroid screen and directly proportional to the velocity, v, of the slit, i.e.

$$\lambda = \frac{v}{f_m} \tag{1}$$

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* $I_m = k + \sin 2\pi x/\lambda$ where I_m is the intensity at a distance x from the start of the scan and λ is the distance corresponding to one cycle of intensity variation. As the intensity cannot have a negative value for any value of x, k is a constant equal to or greater than 1.

in the case under review λ may be simply determined from the ratio of the total length of slit travel to the total number of patterns, i.e.

$$\lambda = \frac{15}{24} = 0{\cdot}625 \text{ mm}$$

If $v = 1{\cdot}875$ mm per minute and $\lambda = 0{\cdot}625$ mm, then from equation (1),

$$f_m = \frac{1{\cdot}875}{0{\cdot}625} = 3 \text{ cycles per minute}$$

As there are two cycles of modulation for each complete rotation of the polaroid screen, this gives the screen a final drive speed of 1·5 rev/min. As discussed in Section 3.3 the overall gear reduction employed from the motor to the polaroid screen was 200 : 1, therefore, for 1·5 rev/min of the polaroid, the motor speed had to be 300 rev/min. The normal synchronous motor speed was 200 rev/min at 50 c/s, it was therefore necessary to adjust the frequency of the supply generator to 75 c/s to give the required 300 rev/min.

From the specification given in Table 1, the density of the bars was 0·55 min. to 1·05 max., a range of 0·55. For ease of working it was decided that the master negative would be made by blue light on a non-colour-sensitive material.* The density range of the polaroids to blue light was therefore measured and the results are given in Table 2.

TABLE 2

Measured Density Range of Polaroid Screen Unit

Min.	0·7
Max.	2·27
Density Range	1·57

These are diffuse densities to blue light using a Wratten 47B Filter.

Using the polaroid filter and travelling slit a series of exposures was made on B40 plates with a finite increase in slit width for each exposure. From the measurements obtained a curve was plotted relating the range of densities produced for a given width of slit; the velocity of the slit and speed of rotation of the polaroid filters remaining constant. It was observed that this curve followed the form of $\sin \theta/\theta$ (where θ is expressed in radians) as shown in Fig. 8. The geometrical and mathematical treatments from which this form of curve may also be derived are adequately described elsewhere[3,4] as similar conditions apply in the scanning of variable-width sound tracks on cine film and in aperture distortion in television camera tubes.

From Fig. 8 it will also be seen that the curve descends from a maximum density of 1·57 and crosses the line of zero density range (zero modulation) when the slit covers its own width in the time taken for one complete cycle of modulation

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* Of the various materials tested, Kodak B40 plates were one type found to be suitable.

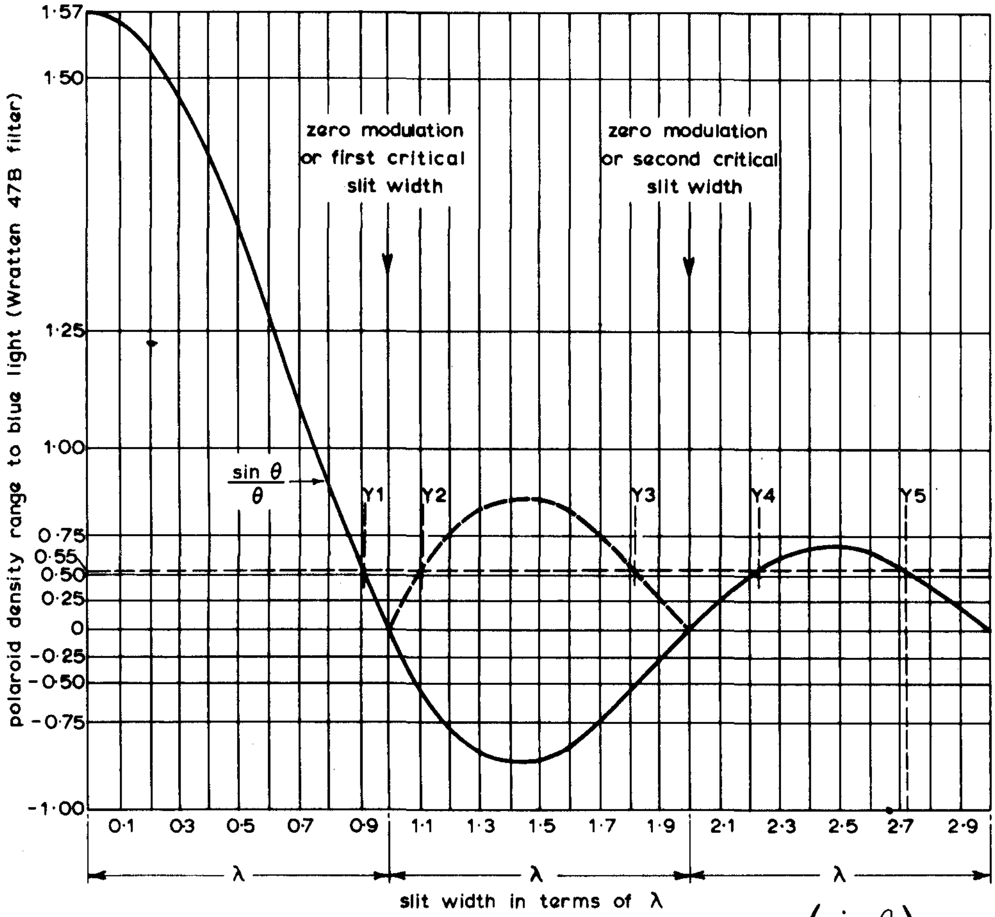

Fig. 8 - A plot of density range versus slit width $\left(\frac{\sin\theta}{\theta}\right)$

produced by the polaroid filters or when λ = slit width, and this zero modulation or critical slit width occurs for any integer relationship of slit width to pattern wavelength. Between these points of zero modulation there exist therefore along the curve a number of points Y_1 to Y_5 where the density range required, i.e. 0·55 may be obtained. In practice for the reasons given in Section 3.5, the widest slit possible was preferred, so point Y_5 was chosen, giving a slit width of 2·75λ or 1·7 mm where λ = 0·625 mm.

5.2. Development

To achieve a gamma of one on the B40 plates a development time of six minutes in Kodak D76 at 68°F (20°C) was found to be optimum, this time being long enough to enable an accurate and reproducible result to be obtained with controlled manual agitation. The characteristic curve of the Kodak B40 plates under these conditions is shown in Fig. 9.

5.3. Density Measurement

As the image density of the bars on the master negative varied continuously, it was necessary to use a microdensitometer to carry out the measurements. In order

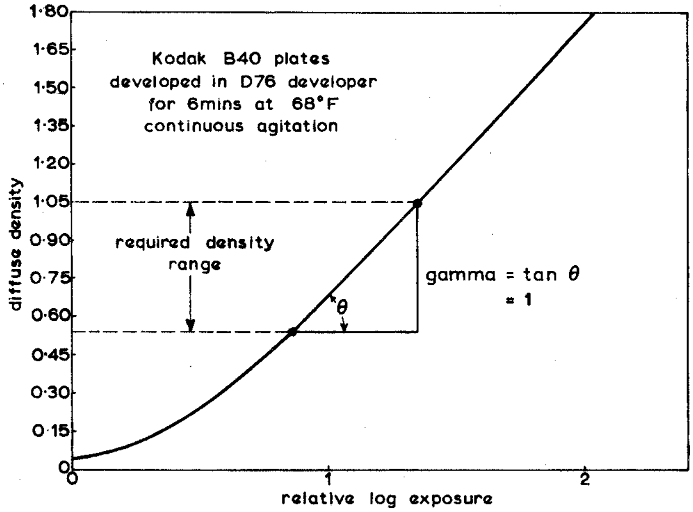

Fig. 9

A characteristic curve of Kodak B40 plates

to relate the specular density readings obtained by a microdensitometer to the single-diffuse density required, a graduated series of exposures was also made on a Kodak B40 plate which was similarly developed to a gamma of one. This plate was then measured using a microdensitometer and also a densitometer capable of measuring diffuse density. The results are shown in Fig. 10. The relationship between diffuse density D_d and specular density D_s is known as the Callier coefficient D_s/D_d and varies according to the density being measured.

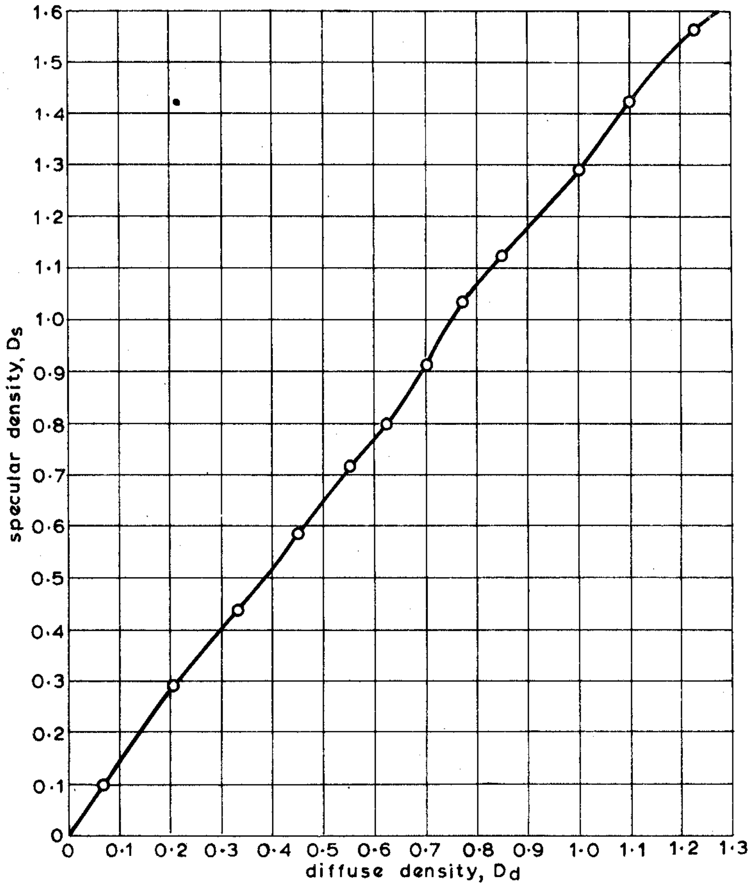

Fig. 10

A plot of the Callier coefficient of a processed B40 plate

6. THE PRODUCTION OF SINE-WAVE BARS OF REFLECTANCE: TEST CARDS 'D' AND 'E'

6.1. Practical Considerations

The final requirement for the sine-wave bars was their production on bromide paper to the specification given in Table 1. As a master negative had now been obtained with the correct density range, it was necessary to print from it the different frequency bars at the correct magnification. It was also essential that the bromide print obtained should be developed to a gamma of one.

6.2. Print Material and Processing

An inspection of manufacturers' curves showing the characteristics of printing papers revealed that with certain chlorobromide emulsions it should be possible to achieve unity gamma. It was found experimentally that by using Kodak Bromesko WSG.1S paper and developing it as shown below, a gamma of one could be achieved.

Developing Agent:	Kodak Soft Gradation
Dilution by volume:	1 : 3
Time:	1½ minutes
Temperature:	68°F (20°C)

From a range of density steps produced on the B40 plate it was found that the straight line portion encompassed the density range required of 0·5 to 1·05 as shown in Fig. 11.

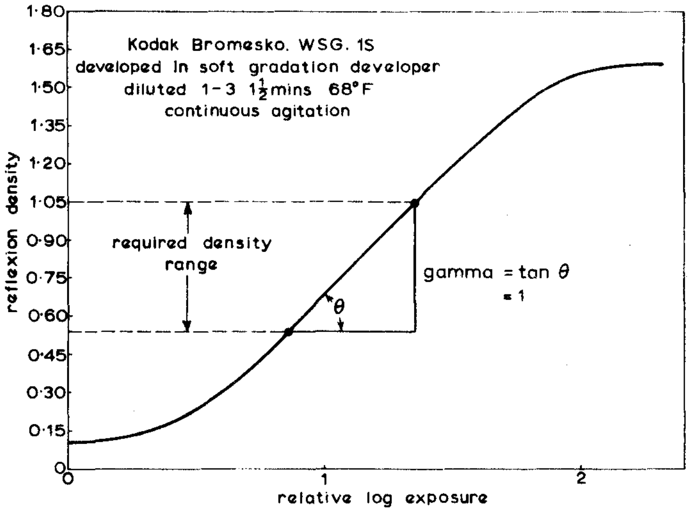

Fig. 11

A characteristic curve of Kodak Bromesko WSG.1S paper

In an attempt to ensure consistent results the exposure and processing conformed to the following conditions:-

(a) The enlarger lamp was fed from a stabilized supply

(b) All the chlorobromide paper came from the same batch

(c) All the exposed prints were first soaked in water before processing

(d) Fresh developer was used for each print

(e) The method of agitation was strictly controlled so as to be the same for each development.

6.3. Measurement

One of the more difficult problems encountered was the task of measuring the variable reflexion densities of the sine-wave bar patterns. The reflexion densitometer available could measure a minimum width of approximately 1 cm; but on the bar patterns the distance to be measured to disclose the different density levels had, in theory, to be infinitesimal. As it was possible to produce relatively large area density patches and these could be calibrated, it was decided to use a comparative system of reflexion density measurement.

A Zeiss binocular microscope was obtained. This instrument enabled a specimen area of only 1 mm in diameter to be measured. A built-in tungsten light source was used to illuminate the specimen. A photo-resistive cell was fitted to one of the eyepieces and its output fed to a microammeter. Using this apparatus it was possible to effect a comparison between the specimen and the previously calibrated density patches. It was essential to use a glazed paper specimen, as serious trouble was encountered when using unglazed material owing to the random specular highlights caused by the irregular surface of the paper.

Although this technique had its limitations, it enabled a close method of density determination to be made on a comparative basis. The final measurements were made by displaying the known density patches alongside the blocks of bars in front of an image-orthicon television camera. This camera was operating in a linear mode under carefully controlled conditions of illumination. The electrical output waveform was displayed on an oscilloscope from which measurements could be made. Table 3 indicates the results that were obtained for Test Card ‘E’.

TABLE 3

FREQUENCY	WHITE LEVEL	BLACK LEVEL	MODULATION
1·5 Mc/s	12·5	1·3	11·2
2·5 Mc/s	12·4	1·2	11·2
3·5 Mc/s	12·3	1·2	11·1
4·0 Mc/s	12·3	1·2	11·1
4·5 Mc/s	12·5	1·4	11·1
5·25 Mc/s	12·2	1·2	11·0

Density 0·5 = 12·3 arbitrary units

Density 1·05 = 1·2 arbitrary units

6.4. Bar Pattern Dimensional Measurements

The bar patterns were checked overall by a travelling microscope, and they were found to be within 2% of the required dimensions.

6.5. Final Bar Patterns

The need for optimum quality bar patterns meant that in some instances re-washing and drying a print could make it acceptable. In many cases chemical reduction of the image was used in order to remove density and bring the bars within the specified range. Fig. 12 shows one example of the final sine-wave bar patterns.

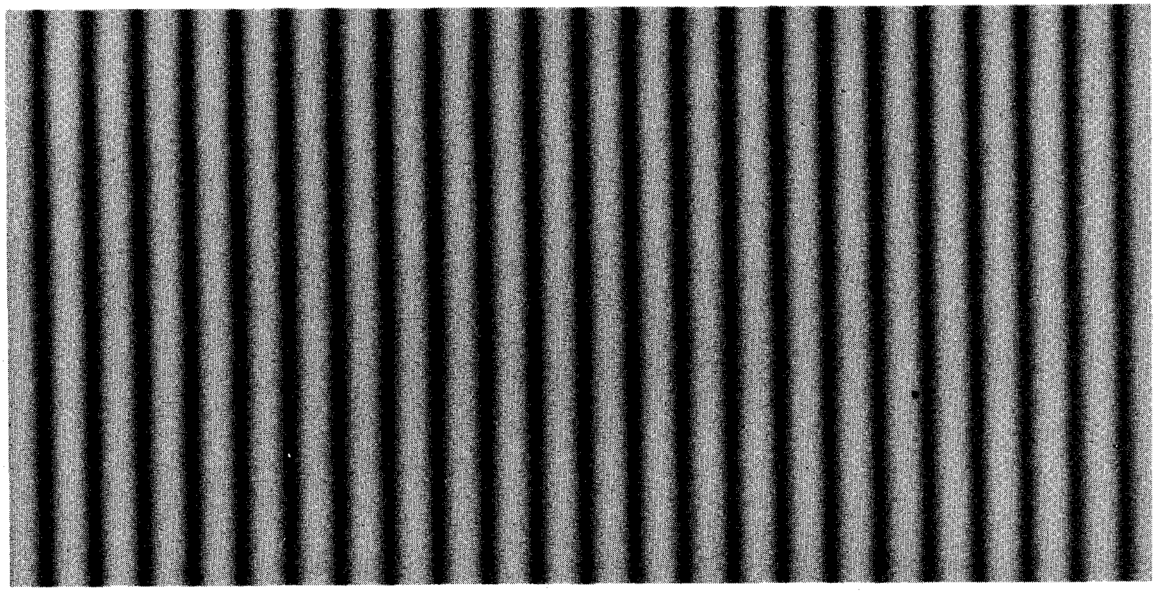

Fig. 12 - An example of the final sine-wave bar patterns

6.6. The Mounting of the Bar Patterns and Background: Test Card 'E'

Owing to some problems encountered in the transmission of Test Card 'D', it was decided that each block of bar patterns for Test Card 'E' should commence and finish at the mid-specific density value of 0·72; the blocks of patterns were therefore mounted on a grey background of this density.

7. CONCLUSIONS

By the use of a precision photographic enlarger coupled with a means of accurately controlling the light source, the scanning system and the processing of the exposed image, it is possible to produce bar patterns having a sinusoidal distribution within the specification required. The greatest limitation was due to the employment of a paper-based emulsion to meet the need for a reflexion copy. It is realized that improved results could be obtained on high-stability film material, should the need arise for a transmission type of copy.

8. ACKNOWLEDGEMENTS

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